Defense Technical Information Center
Compilation Part Notice

ADP014144

TITLE: Collaborative Product Development Supported by Modelling and Simulation

DISTRIBUTION: Approved for public release, distribution unlimited
Availability: Hard copy only.

This paper is part of the following report:

TITLE: Reduction of Military Vehicle Acquisition Time and Cost through Advanced Modelling and Virtual Simulation [La reduction des couts et des delais d'acquisition des vehicules militaires par la modelisation avancee et la simulation de produit virtuel]

To order the complete compilation report, use: ADA415759

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP014142 thru ADP014198

Click here to view slide presentation presented in PDF format

Collaborative Product Development Supported by Modelling and Simulation

Billy Fredriksson
Saab AB
Saab Aerospace
S-581 88 Linkoping
Sweden
billy.fredriksson@saab.se

Gunnar Holmberg
Saab AB
Saab Aerospace
S-581 88 Linkoping
Sweden
gunnar.holmberg@saab.se

Johan Lilliecreutz
Center for Market Analysis
Teknikringen 1E
S-583 30 Linkoping
Sweden
johan.lilliecreutz@cma.nu

Abstract

The development of aircraft involves many actors throughout the supply chain. The rationale for forming partnerships and selecting suppliers ranges from risk sharing, knowledge access to price and reliability of supply. The product, subject to many design drivers, uses a wide range of technologies in highly optimized conditions with ever-increasing cost pressure. The lifetime for technologies and subsystems, clockspeed, ranges over more than an order of magnitude between software functionality and airframe life while the functional integrity of the product has to remain throughout its life. This is implying a strong need for efficient collaboration throughout the supply chain supporting product integrity throughout its life.

The purpose of this paper is to show how modelling and simulation, M&S have been applied systematically as an enabler for Holistic Integrated Product Development at Saab. Early knowledge and understanding as well as ability to communicate through- out the supply chain play a critical role.

The findings are based on the research program LARP (initially Lean Aircraft Research Program) and the implementation experiences from Holistic Integrated Product Development at Saab. Studied cases include the auxiliary power unit development, a collaborative project with challenging integration both on functional and physical level. Results are demonstrating e.g. the importance of M&S for successful communication and coordination between integrator and supplier. The findings further high-lights the importance of creating value at early stages of product development, including New Business Models for Aerospace& Defense, Flexible Product Development and Supply Chain Innovation. All these subjects are studied in the current phase of LARP.

Background

Defence budgets have been subject to repeated cuts over a long time, forcing the governments and industries to act in order to ensure sufficient defence materiel supply as well as profitability for the industry. The self supply within single countries is reduced and international collaboration becomes a pre-requisite for the development of complex systems like aircraft. Drivers are both technology supply and competitiveness. This and other factors have led to a globalisation, where international companies, partnerships and supply chains are designed and created based on a rationale ranging from cost- and risk-sharing to knowledge access, technology supply and reliability of supply in general.

Possibilities in modelling and simulation, M&S, and information technology together with improved development practices support a move towards a focus on early stages of development, where much more effort is spent on initial studies before a program is started in order to reduce risk and the overall defence cost. This so called Simulation Based Acquisition, SBA <1>, is changing the business environment as the upfront investment is growing, while downstream programs could be expected to be in smaller series, less frequent and require more flexibility and adaptability.

Defence systems are used in an increasingly complex context. A growing flexibility in the type of operations is important where new types of interoperability is needed in order to be able to combine different defence

Paper presented at the RTO AVT Symposium on "Reduction of Military Vehicle Acquisition Time and Cost through Advanced Modelling and Virtual Simulation", held in Paris, France, 22-25 April 2002, and published in RTO-MP-089.

systems and achieve the increasing level of integration required to support the operation. Like most complex systems, the overall life cycle for defence systems is an order of magnitude longer than for some of the sub-systems it is composed of <2>. This implies that issues like obsolescence and changing requirements are driving a need for an easily upgradable system in order to ensure the required functionality and integrity of the system. Technologies and systems are growing in complexity and the investment for being able to introduce a new solution is growing.

From the above it is clear that the development of complex defence systems are facing several challenges. The context is ever changing, the product is growing in complexity, the cost pressure is increasing and the co-developing supply chain is becoming increasingly complex. In order to meet this situation, and to be able to continuously adapt, Saab has applied strategies such as Holistic Product Development <3> and Integrated Product Development <4>, IPD. We have been working together with universities in the Lean Aircraft Research Program, LARP <5> to support the reengineering of the industrial process. Some important aspects have been to support early knowledge, communication and teamwork through-out the supply chain. An important enabler to all these changes have shown to be M&S.

The purpose of this paper is to show how M&S have been applied systematically as an enabler for Holistic Integrated Product Development at Saab. Early knowledge and understanding as well as ability to communicate through- out the supply chain play a critical role.

LARP

LARP Overview

In many industries the leading prime contractors have now come to a point where they focus on their role as systems integrators. They are concentrating their design and production resources on core competencies and areas of strategic importance for the customers recognition of the brand image and identity of the product. Some of them will develop partnership relations with several competing manufacturers. In the most developed stage of partnership relations the supplier will be expected to act as if it was a subsidiary or division of the buying firm, i.e. almost back to vertical integration or hierarchies again after a wave of outsourcing. The systems integrators are developing new organizational patterns in order to reach the same or more efficient structures than if they would incorporate the most important suppliers.

The purpose and goal with LARP was *from a systems integrator perspective to develop models, methodologies and tools for efficient relationships between a systems integrator, customers and its major suppliers in the aerospace industry*. The empirical reality in LARP was two separate systems, APU (Auxiliary Power Unit) and GECU (General systems Electronic Control Unit), within the JAS 39 Gripen. The systems have been studied in depth since 1997 by a research group from Linköping university and the two graduates schools. IMIE (International Graduate School of Management and Industrial Engineering) is an alliance of thirteen divisions which represent a broad and interdisciplinary competence within management and industrial engineering. The other graduate school was ENDREA (The Swedish Engineering Design Research and Education Agenda) which focus is on developing, adapting and implementing theories and methods for managing and conducting world class product development in the manufacturing industry. Aerospace industry has been the industrial partner.

From a systems integrators (Saab Aerospace) view four research perspectives (subprojects) were highlighted; relations to the customer, relations to major suppliers, project management aspects and collaborative product development. The results from the studies have been presented in several academic thesis (PhD and Licentiate) and conference papers (see references) and in an edited book version <5>. The major conclusions from the four perspectives are summarized below.

Relation to the customer

An important aspect in the relation with the customer is marketing and related activities such as offset. Offset, an advanced form of counter trade is common in the international marketing of large infrastructure and defence systems. Offsets are activities that benefit the buying country for example in the form of local content, support of exports, subcontracts and technology transfer. Based on eight case studies of marketing of

large defence systems <6>, four models are developed to describe the offer, the seller, the buyer and the buyer-seller interaction. This sub-project is not further addressed in this paper.

Relations to major suppliers

These studies on relations to major suppliers <7,8> covered both existing relations and relations under transition due to changes in the systems integrators make or buy strategy, i.e transfer of an activity or outsourcing. They demonstrate the importance of differentiation in the supply base as well as the importance to continuously revisit the supply base strategy through- out the system life cycle.

The increased focus on lean production indicates a need for breaking each relation into bits and pieces, a strategy that influences both buyer and supplier. If there is a serious focus on lean supply and supply chain management, there also should be a focus on how to treat the supplier base. The lean supply strategy indicates that the entire supplier base should be treated similarly in order to obtain full efficiency. Characteristic of the lean supply relation is a clearer integration between buyers and suppliers, not necessarily meaning cross-ownership. The lean suppliers are early involved in product development and are expected, thereby, to participate actively in the buyer's development of new models.

When analysing the supplier base in the aerospace industry, we see a broad spectrum of system and technology levels - from the traditional sub-contractor of components to a sophisticated and closely integrated systems supplier. The hypothesis is that every supplier and relationship has different characteristics and therefore a different need for integration. Treating every relationship in the same way is not an efficient purchasing strategy. Lean production has in numerous studies been presented as "the way of the future" to handle increased competition. In a sense, *differentiation of existing supplier relations* could be a way to achieve efficiency.

Previous research on the phenomenon of outsourcing has mainly focused on strategic considerations. Nevertheless, the process of carrying out the transfer of an activity from being internally controlled to becoming externally managed may prove to be equally difficult because of interdependencies at the operational level. The most important existing outsourcing concepts were criticized for being based on an overly rational and static view of their core competence foundation, for failing to acknowledge the implications of strategic level versus operational level considerations, and for being overly deterministic.

An alternative outsourcing *process model* <8>, explicitly emphasizing the inter-linkage of make-buy decisions and transfer of control, transfer activities may lead to specific implicit make-buy decisions, i.e. that may not be perceived of as outright decisions. It was further argued that it is difficult to perceive of the final outcome of outsourcing when conceiving make-buy decisions, making it difficult to manage and control. Rather, a process of recurring sets of linked and dependent incremental make-buy decisions transfer activities to be managed in accordance with the outsourcing vision. Only a direction can be identified, whereas a clear goal cannot be defined beforehand, suggesting that continuous strategy adjustment and appraisal are necessary actions, was advanced as a potentially more accurate model of outsourcing.

Project Management

This sub- project <10,11> have studied how to manage complexity in projects initially from an intra-organisational and later from an inter-organisational perspective. It provides tools to analyze and design the organisation of projects such that team efficiency, concurrency and collaborative structure can be optimised from a communication perspective.

A collaboration is taking place on several levels (i.e. strategic, tactical and operational). This research is pointing at the importance of having these levels supported by relevant structural mechanisms and methods.

One of the key difficulties is to achieve a Work Breakdown Structure, WBS, that is suitable for the actual collaboration scenario and product architecture. A methodology called Dependence Structure Matrix , DSM <9>, is introduced and applied to support this. DSM allows for analysis of the possible WBS solutions and architectural decompositions such that e.g. team tasks could be identified and communication need understood.

It has been shown that the method supports the design of the organisation, the identification of WBS:s that are more straight forward to assign to different teams, and that communication need will be better and earlier

understood. The work to establish the DSM- matrix should be participatory as it serves as a catalyst for the strategic dialogue between the parties and levels of collaboration.

Collaborative Product Development

Model based product development have been studied in a collaborative context <12>. These studies demonstrates the potential and maturity of functional modelling of specifications and analyses the need for a project web in collaborative product development.

A good quality, well understood specification is an instrumental prerequisite to efficient product development. The specification of complex systems have often suffered from the difficulty to express with sufficient precision and consistency its functional behaviour using natural language. This problem is accentuating in importance the more parties that are using the specification.

Here functional modelling have been applied as a specification tool and the intended behaviour of a number of systems have been modelled, both systems being developed in-house and by suppliers/ partners.

The research have shown that functional modelling is mature enough for systematic application. It has been shown that the use of a modelled specification generated a better specification than the textual one, as it detected inconsistencies at early stages. Further, in collaborative projects it has been shown that the common development of the model have accelerated the mutual understanding of the system and its behaviour in the total system.

In collaborative product development, large amounts of project information is exchanged which is not direct product documentation. In order to support this, attempts were made to implement a project web that could support the management of the development project <13>. As this was made in 1996-97 several difficulties appeared, among these immature internet technology and difficulty to guarantee security of information. A conclusion is that there is potential for a project web when IT- security can be achieved and approved.

Holistic and Integrated Product Development

The application of Holistic and Integrated Product Development, IPD, have been important approaches to improve performance and cost effectiveness for the development processes at Saab during recent years <3,4>. These provide a structured approach on how to improve the development capability, inspired by e.g. <14,15 >. The implementation of IPD has used an enabling approach with a starting point in maximising the individuals ability to contribute to and support a rapid convergence to feasible designs in a life cycle perspective.

"IPD is a structured way to maximise the contribution from people, processes and tools to achieve product optimality"

Where product optimality reflects the balance between cost and performance that best meets customer demands. In the design of this development process at Saab some aspects have been central:

- Provide easy access to information and knowledge
- Use M&S extensively to provide knowledge support to engineers in early development stages in order to allow for mature decisions as early as possible.
- Good and well understood specifications.
- Minimise the lead-time from decision to delivery.
- Support and simplify vertical and horizontal communication internally and externally.
- Provide ability for the engineers and experts to utilise their expertise in an efficient manner
- Promote Decision ability

The process is designed to easily and early bring in new expertise and easily start interaction with the purpose to achieve a possibility to dynamically allocate expertise into projects, e.g. customers, suppliers and shop-floor people and let them contribute to the product at early stages. This is more extensively reported in <3,4>.

Development Rooms

The team members are working together and sharing information in order to agree on the best common design solutions covering all design drivers and constraints. In order to achieve this, the team uses computer based information and M&S. Current levels of technologies allows for the possibility to support interactivity to a large extent. Not only can models be selected and viewed within less than a minute in complex products, but changes can also be introduced in a meeting. Quick interference checks could be performed, linear analysis could be made, given limited mesh change needs and so on.

Based on the above, a development room has been designed, where two workstations and one PC provide computer power, two large screen projectors give the ability to view two of the three computers information simultaneously for the full team. The computers are normal installations on the network with ability to use any system and data available on the network given that the team have access authority. Following the success of this tool, a number of these rooms have been built.

This enables the team to work, in the room, viewing the design in its context e.g. from the CAD-system on one screen and discuss some type of issue or opportunity. On the other screen additional information available on the network can be viewed depending on the needs. Typical examples are bill of material, BOM, or other Product Data management Information, PDM, analysis, simulation or scheduling information. Changes can be introduced and to some extent analysed interactively.

Bringing the use of these development rooms into the team environment provided support for more dynamics in the meeting. The use of the tools, combined with the goal to improve the ability to reach joint decisions in the team, lead to the design of a methodology to take "action like" minutes from the meetings. A particular structure was formed, and tools were developed to support this. Initially the methodology was supported by standard "Office" software which was found not to be sufficiently efficient in a networked environment. To improve efficiency an early web-application was created.

This minutes application uses "screen grab" technology to allow users to pick any information from the computer screen and add it to the web minutes with texts, pictures, annotations as well as action items such as identification of responsible and date of completion during the meeting. An integrated archiving functionality is provided with the ability to follow design rationale from specification to released and verified product definitions. Several generations of the application have been developed and there is a continuous demand for more information to be handled within the application, e.g. scheduling. A current challenge is to identify support for easy search in the archive in order to promote reuse of earlier engineering solutions in new applications.

The Digital Mock Up, DMU, is the most frequently used model to discuss around in the rooms. The current technology implemented on the IPD-level includes exact solids CAD on workstations, high performance visualisation, simulation, analysis and retrieval tools and a model structure with one part instance in each model which allows a flexible and rapid build up of different context scenarios. The PDM support available in early stages of development is still limited. The weak area in the current solution is the somewhat cumbersome establishment of models for different product configurations. The requirements on the PDM-system to make progress in this area includes e.g. being able to master many concepts subject to intense change and provide good retrieval and analysis capabilities to compare the pro's and con's of the different concepts.
Furthermore, the manning of a team often consist of a core of people from the major disciplines, while they need to expand the team for particular tasks where additional expertise is needed, such as bringing in suppliers or customers. It is therefore important to provide good support, not only for the team to understand the product, but also to give them the ability to easily involve other people. The development rooms, the DMU and the visualisation tools are playing a significant role for this ability.

Analysis and Simulation

Analysis and simulation in a wide sense covers areas from system functional modelling, concepts, stressing and aerodynamics to assembly , shop floor simulation and maintenance and mission support. Many areas of

analysis have improved during the last decades where different performance aspects have become much more predictable.

The improved predictability has probably influenced the design decisions in the early stages of development such that it has been easier to justify a solution from a performance or functional point of view, rather than from a cost or manufacturability view.

Only in the last decade have areas such as assembly simulation and other manufacturing related simulations been able to contribute with sufficiently short response time to match performance simulations at early stages. This is a very fortunate development contributing to the balance in the team that has to be taken further, in order to meet the demand from the continuous movement towards more cost focused design criteria.

If the information provided fails to balance the level of consideration in the design criteria, which normally is the case, this need to be met through other efforts. One method utilised is the use of the different roles in the team, and try to strengthen the ability to influence decisions for people from disciplines having lower level of quality information available .

An example is that in early stages the manufacturing engineer could have difficulties in catching up with the consequences of design decisions. By making him/ her the one who runs the web based application for taking minutes from the meetings, he/ she can to some extent control the flow and have all possibility to influence the design from the very beginning.

Another issue in the same category is that different disciplines are progressing based on different information, which sometimes makes it difficult to maximise the profits from he concurrent development, e.g. the stress engineer is approaching the product in a different break-down approach than the systems installation engineer or the manufacturing engineer. Co-ordination is therefore needed during the evolution of the product in order to avoid decisions focusing on a limited set of design drivers due to the lack of certain types of information.

In general, models for analysis and simulation are considered as a part of a model concept where the models are established in early stages of design and maintained throughout the life cycle in order to remain as the main information carrier for the product aspect concerned. Early models are often mathematical simulations to be refined and correlated with experimental data or experience from application later on (e.g. ground vibration test for eigenfrequencies, manufacturing cost for costing or operational properties). The model concept serves as a strategy to make the best use of available information.

Supplier/ partner Integration

Since a high degree of the aircraft content is developed and supplied by other sources than the system integrator, it is important to achieve interaction mechanisms which supports co-ordination, where needed. Obviously this integration is dependent on how decomposable the work is. The first operational step is always to minimise the interaction needed between the parties. The next step is to identify which information is important to co-ordinate/ exchange and at what frequency it needs to be co-ordinated. At Saab we have basically worked with three levels of technology for integration

1: e-mail and file transfer
2: replication of data sets at a certain frequency
3: remote clients with shared databases

Sorting on these levels appear to be sufficient from an IT point of view. The difficulty is almost always to resolve security issues. The level of technology becomes a prerequisite for the type of methodology and tools that are needed to achieve a collaborative support. Often, a low technology level is driving increased complexity in the methodology in order to ensure e.g. configuration management. A practical level is normally level 2 where the selected DMU and analysis data are replicated at the supplier site with maximum delay of some hours. The same applies for the project web, as described above, as well as for planning information and so on. Information produced at the supplier site is released to the data storage at Saab.

The many supplier and partner relations that follows from the involvement in several aircraft projects with several partners drive the complexity of the company operations. In order to minimise this complexity and maintain the ability to optimise the performance of operations a strategy is used where clear interfaces are applied with limited impact on internal processes.

Concluding discussion

The situation of tomorrow for a systems integrator is characterized by aspects such as a wide range of integrated technology content with varying clockspeed, many design drivers, late definition of technologies and adaptability need. The systems integrators ability to handle intra and inter organizational relations, scalability, ability for growth and adaptability, knowledge management and shaping a value creation culture are of importance.

The application of lean principles to projects increases the ability to master lead time and cost. In order to have the right conditions for a lean project it is assumed that fundamental design decisions are taken at an early stage, ahead of the lean project. The arrival at this starting point, often referred to as having the architecture or layout of the product and its subsystem solutions and technologies ready for application, is not supported by the lean paradigm <16,17,18>. These aspects combined with the incentives to focus the effort at early stages according to SBA are all pointing towards the importance of the ability to make good design judgements at early stages. Furthermore, much of the innovation field has to be at initial stages as this is where the design freedom exists such that new values can be created with low cost and project implications, ahead of the lean projects having a starting point where many fundamental design decisions have been taken.

<u>Constructive lean</u>

The lean paradigm that focuses on up-front value creation through-out the supply chain or value network, we have chosen to label *constructive lean*. The challenge for constructive lean is to create the right environment for the whole supply chain at early stages to generate value and achieve the right conditions for a lean project. If this fails, there is a clear risk that only the traditional down-stream lean project remains. This could become a long term threat for the company as it only allows for current systems to generate profit by continuous cost and resource reduction, but does not stimulate the achievement of new competitive systems supporting the long term development of the company, a situation we label *anorectic lean*. The traditional lean project is still an important component of constructive lean, as the way to bring a new system to completion when it is through its architectural phase.

<u>LARP Future Direction</u>

The continuation of LARP is based on the constructive lean approach. The redirection of the Swedish defence into a Net Centric Warfare paradigm means e.g. that systems have to support a more flexible use and integration with other systems. Furthermore, the whole system of systems will be subject to continuous change, and all involved systems will need to adapt and be able to federate with a wide range of systems over time. The continued research will be focusing on the following four topics in order to further develop the constructive lean approach:

New Business Models

Current Defence acquisition strategies, e.g. Simulation Based Acquisition <1>, are moving in a direction where the effort both from the customer and from the integrator is increasing at early stages. This is changing the conditions for defence business. In this project possible business models are studied in order to identify models providing best incentives for all involved parties.

Flexible product development

The development and use of complex systems, e.g. defence systems, is subject to long life cycles with changing conditions implying that there is a need for flexibility in the system. The need for flexibility origins in areas such as new innovations, new requirements as well as obsolescence in high clock- speed sub-systems.

The strong connectivity between the development capability and the resulting system solution is stressing the need to have a development capability that is promoting these types of flexibilities. This research is focusing on how to create a framework for flexible product development.

Life cycle value

This project studies what the important aspects are in order to set up a development capability that supports life cycle value implementation in an optimal way. Case studies have been done together with Massachusettes Institute of Technology on several aircraft and a framework for life cycle management is proposed <19>. Studies will continue based on a wider industrial basis.

Supply chain innovation

The main driver in the area of *supply chain innovation* has its origins in the interaction between prime and SME. Here are some examples. First, development of more complex projects and systems, often fully integrated, stresses the importance of early access to technology and innovations. Second, the procurement strategy is focusing on a small supplier base with fewer and larger suppliers, which hinders the surveillance and acquisition of new technologies, often driven by SME:s. Third, the difference in size between prime and SME:s do not support effective risk and profit sharing and transferring of knowledge in early RTD phases of large projects. Important questions between systems integrators and the supply chain are; what are the incentives and initiatives? How is the interaction and interdependencies?

<u>Collaborative Product Development</u>

In the implementation of current development practices we have aimed at achieving a constructive lean ability which is enabling all involved parties to contribute at their best to the system solution in a life cycle perspective. In order to achieve this, team capabilities, collaboration and ability to achieve qualified design decisions early in the development cycle have been instrumental.

To improve the team capabilities we have built development rooms using M&S to support the team communication and allow for interaction with models during meetings. Intranet solutions have been used to help in decision making. The enabling approach which is focusing on providing value for end users at different levels such that a demand for the supporting methods and tools is important in order to achieve a wide implementation. The only obstacle to this approach found so far is when there is a long distance between people feeding an application with information and the people benefiting from the application.

The involvement of external parties in the team, co-located collaboration, have demonstrated the importance of models to support communication. As different organisations using different terminology, or even languages, it is necessary to provide the best support in order to reduce the risk for miss- understandings. M&S is reducing this risk both between organisations and within one organisation between e.g. design and manufacturing people. Functional modelling is contributing strongly to a better specification which is also better understood when developed together between e.g. integrator and supplier.

The integrated use of M&S through- out the supply chain, in distributed collaboration, implies a number of integration difficulties. Important is to maintain an internal process that is applicable to many projects and can be interfaced to other processes, such that the possibilities remain to upgrade and optimise the internal process without having to simultaneously propagate this change through the supply chain. This is supported by the LARP process for implementation of a collaboration. The results from the sub-projects Project Management and Collaborative Product Development have together with Saab experiences from collaborative projects applying IPD served as the basis for the LARP recommended process of implementing a collaborative development project. This process starts with the analysis of possibilities and constraints in the possible WBS and its distribution. Then DSM is applied in order to identify best possible WBS minimizing the communication need between enterprises. Following this IPD support is implemented in order to support the needed level of communication.

The early understanding of the consequences of early design decisions is key to the constructive lean environment. This understanding is a combination of experience from earlier projects, M&S as well as the teams ability to make the synthesis of the knowledge of its individual members. As M&S contains incomplete knowledge, it is important to use it together with other available information, such as experience and physical testing. The above described model concept which is combining the different sources of information throughout the life cycle provides a mechanism to federate information and also bring it into new projects to enable the use of earlier experience.

Conclusion

The business environment for complex defence systems is changing in a direction where early value creation and communication through- out the supply chain is playing an increasingly critical role. M&S is a key enabler for early value creation and communication through- out the supply chain in collaborative product development.

Abbreviations

IPD	Integrated Product Development
LARP	Lean Aircraft Research Program
M&S	Modelling and Simulation
RTD	Research and Technology Development
SBA	Simulation Based Acquisition
SME	Small to Medium size Enterprises

Referenses

<1> Frost R, (1998), *Simulation Based Acquisition –An Ongoing Outlook-*, Simulation Interoperability Workshop, Fall 1998.

<2> Fine, C (1998), *Clockspeed- Winning Industry Control in the Age of Temporary Advantage*, Perseus Books.

<3> Fredriksson B., *Holistic Systems Engineering in Product Development*, Military Aircraft, 1995.

<4> Holmberg, G., (2000), *Integrated Product Development - A key to Affordability*, ICAS 2000, Harrogate, UK

<5> Lilliecreutz, J. & Holmberg, G., (eds.) (2000), *Constructive Lean - A Systems Integrators Perspective. The Relationships of Tomorrow Between Systems Integrators, Customers and Their Major Suppliers In the Aerospace Industry Findings from LARP part I.* Research Report from Linköping university and Saab AB Linköping, April, 2000.

<6> Ahlström, M., (2000), "Offset Management for Large Systems - A Multibusiness Marketing Activity", Linköping Studies in Management and Economics, Dissertations, No. 46, Linköping university.

<7> Lilliecreutz, J. & Ydreskog, L. (1999), Supplier Classification as an Enabler for a Differentiated Purchasing Strategy, Selected Conference Paper for publishing in International Journal of Purchasing and Supply Management – Special Edition and also in Global Purchasing & Supply Chain Management World Market Research Report.

<8> Wasner, R. (1999) "The Outsourcing Process –Strategic and Operational Realities," Licentiate Thesis No. 163, Linköping university.

<9> Eppinger, S.D. & Ulrich, K. T., (1995) Product Design and Development, McGraw-Hill Inc. New York.

<10> Danilovic, M (2001), *Supplier Integration in Product Development*, The 10th International Annual IPSERA Conference 2001.

<11> Danilovic, M (1999), *Loop – Leadership and Organization in Integrated Product Development,* PhD-Thesis, Linköping university.

<12> Backlund, G., (2000), *Modeling Requirements in Systems Development - a Way to Manage Complexity*, Licentiate Thesis, Linköping university

<13> Öhrwall Rönnbäck, A. (1999), *The Information Infrastructure in Collaborative Product Development*, Licentiate Thesis, Linköping university

<14> Suh, N (1990), *The Principles of Design*, Oxford university Press.

<15> Allen, T (1977), *Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information Within the R&D Organization*, MIT Boston.

<16> Womack, J; Jones, D; and Roos, D. (1990), *The Machine that Changed the World*, Rawson.

<17> Womack, J; Jones, D; and Roos, D. (1996), *Lean Thinking*, Simon&Schuster

<18> Murman E. M.; Walton, M; Rebentisch E (2000), *Challenges in the Better Faster Cheaper Era of Aeronautical Design, Engineering and Manufacturing*, ICAS 2000, Harrogate, UK. To appear in the Aeronautical Journal.

<19> Hallander, I & Stanke, A (2001) *Lifecycle Value Framework for Tactical Aircraft Product Development*, INCOSE 2001, Sydney, Australia.

Paper Keynote #3
Discussor's name S. Woodford
Author Holmberg/Fredriksson

Q: In one of your diagrams, development and production costs increase significantly with time, but operation and support costs do not. Why is this?

A: SAAB has continually tried to minimize the support requirements for their aircraft. With Grippen, they support this aircraft with 1 technician and 2 conscripts from a Road_______. This gives autonomous operation and very low operation and support costs.